′ PATENT SPECIFICATION (11) 1 457 571

1 457 571

(21) Application No. 4598/74 (22) Filed 31 Jan. 1974

(44) Complete Specification published 8 Dec. 1976.

(51) INT. CL.² C12B 1/10 1/12 1/16 // B01F 3/04 7/20

(52) Index at acceptance
C6F 1A 1X
B1C 10 14 18A1 28 4 B1B B2C B2E B3

(72) Inventors CARLYLE SHELDON HERRICK
JAMES JAY SHULL

(19) THE PATENT OFFICE LONDON

(54) IMPROVEMENTS IN MEANS FOR THE OXYGEN/ TEMPERATURE CONTROL OF AEROBIC FERMENTATIONS

(71) We, GENERAL ELECTRIC COMPANY, a corporation organised and existing under the laws of the State of New York, United States of America, of 1 River Road, Schenectady, State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to an apparatus and a process for the conduct of aerobic fermentations.

As used herein, terms such as "gas" and "gaseous" are intended to encompass similar terms indicative of a vapour. The term "growth system" includes the growth medium and those enclosed or defined volumes in flow communication therewith from which gas or gas mixtures may be made available for mixing with the growth medium.

The present invention provides apparatus for the conduct of controlled aerobic fermentations, said apparatus comprising in combination: a growth tank containing a quantity of liquid medium therein for the growth of microorganisms; an agitator located in said growth tank for agitating said medium; a first gas inlet in flow communication with said growth tank for introducing a first gas thereinto; a first gas detector connected to said first gas inlet for controlling the rate of gas admission therethrough; a second gas inlet in flow communication with said growth tank for introducing a second gas thereto; a second gas detector connected to said second gas inlet for controlling the rate of gas admission therethrough; an oxygen sensor located in said growth tank for sensing the molecular oxygen content in said medium; a temperature sensor located in said growth tank for sensing the temperature of said medium; a first gas rate controller being connected to and responsive to signals from said temperature sensor and a second gas rate controller being connected to and responsive to signals from said oxygen sensor.

The present invention also provides a process for the conduct of controlled aerobic fermentations comprising the steps of: a) introducing aerobic microbial culture into an aqueous medium containing requisite nutrients and a source of carbon, b) raising the oxygen content and temperature of said medium to levels at which the microbial culture can grow and multiply, c) continuously sensing the temperature of said medium during the growth cycle, d) continuously sensing the dissolved oxygen content of said medium during the growth cycle, e) mixing a first gas with said medium continuously during at least part of the growth cycle, f) mixing a second gas with said medium continuously during at least part of the growth cycle, said first and second gases being introduced simultaneously during only part of the growth cycle and being intimately mixed during the period of simultaneous introduction, g) automatically controlling the rate of addition of said first gas to said medium in response to the temperature sensing, h) automatically controlling the rate of addition of said second gas to said medium in response to the sensing of dissolved oxygen in said medium, at least said second gas containing at least 20 percent oxygen by volume and said first and second gases being selected from oxygen, air stream, nitrogen and carbon dioxide.

The present invention will be further described, by way of example only, with reference to the accompanying drawings in which:—

Fig. 1 is a three-dimensional view of a first embodiment of this invention;

Fig. 2 is a three-dimensional view of a second embodiment of the instant inven-

tion utilising an extendable/retractable draft tube skirt in combination with an agitating turbine;

Fig. 3 presents graphic illustrations plotted as a function of time period during which a biological reaction is conducted of a) the metabolic heat release (minus heat losses) per unit of time, for a system having a low heat generation rate (relative to the evaporative heat loss) and b) the heat removed by the air bubbles supplied to the system and

Fig. 4 presents graphic illustrations similar to those of Fig. 3 for a system having a high heat generation rate relative to the evaporative heat loss.

Biological reactions generally release heat that may have to be removed in a controlled manner from the reaction mass in order to perpetuate the reaction. Ideally the system would be isothermal.

As air is normally supplied to an agitated liquid medium in an aerobic biological growth system through a sparger or porous plate to meet the oxygen demands thereof, a certain amount of cooling action (sometimes excessive) occurs as a) the bubbles are rapidly heated to the liquid temperature, b) water evaporates into the interior of the bubble from the surface thereof until the vapor pressure in each bubble reaches the equilibrium vapor pressure of water at the bulk liquid temperature, c) oxygen exits and carbon dioxide enters the bubble by diffusion and d) the heat-containing water vapor is removed from the bulk liquid enclosed in the bubbles as they leave the surface. The cooling effect results from the expenditure of latent heat of evaporation by the liquid surrounding each bubble to accomplish the vaporization of water as decribed.

This cooling action has to date been uncontrolled, because it merely accompanies the introduction of the oxygen-containing gas, the rate of flow of which is dictated by the oxygen demand of the biological mass. In a thermophilic system overcooling will usually result from the requisite air flow rate.

This invention optimizes the rate of introduction of the oxygenating gas into the growth system for mixing with the liquid medium and at the same time automatically varies the composition of the oxygenating gas and/or of the bubbles of oxygenating gas. These actions are controlled in response to the temperature and the dissolved (or molecular) oxygen content of the system.

In the apparatus of Fig. 1 an aqueous medium for conduct of an aerobic biological reaction is shown in fermentation tank 10. With the arrangement shown, having established a value for the dissolved oxygen concentration to be used in the growth system (e.g. 1-10 ppm), the amount of oxygenating gas (usually air) introduced through supply conduit 11 is varied as required by automatic actuation of valve 12. The manner of controlling the valve actuator is described hereinbelow.

In this embodiment the air (or pressurized commercial grade oxygen as is described hereinbelow), is discharged into the liquid medium at a point a short distance beneath the center of flat-bladed turbine 14 whereby the maximum amount of bubble surface is developed by the vortices induced around the rotating turbine. The bubbles so formed promote cooling of the aqueous medium by withdrawing latent heat of evaporation therefrom as described hereinabove.

A first gas is introduced into the aqueous medium via gas inlet tube 16 shown concentric with conduit 11 at the discharge end thereof. Pipe 16 serves as the means for the controlled introduction of steam and/or an inert gas, such as nitrogen, into the growth system, the rate of introduction thereof being controlled by automatically actuated valve 17.

As will be described hereinbelow the arangement of sensing and controlling means in Fig. 1 is adapted for either steam/air or air/oxygen operation with the option of introducing supplemental steam or nitrogen. During operation, the requisite amount of dissolved oxygen to meet the biological demand in the growth system is provided by actuation of valve 12 in response to oxygen sensor 18 and controller 19. Oxygen sensor 18 is a commercial unit (e.g. Model E100 Fermentation Design Inc., Allentown, Pa. U.S.A.) for determining the amount of dissolved oxygen in the liquid medium. With controller 19 set, for an operating level for 3 ppm dissolved oxygen, when the oxygen concentration falls below this value, controller 19 will actuate valve 12 to initiate the introduction of air or oxygen into the aqueous system (depending on whether valve 20 or valve 20a is open, the flow rate being set thereby).

The control mode in any of the sensors referred to herein may be such that the rate of introduction of the gas will vary in direct proportion to the offset (the difference between the set point and the reading); and also according to the time integral of the offset and/or according to the time derivative of the offset.

If, during steam/air operation, the input of air (via valve 20) required to maintain the set point level of dissolved (molecular) oxygen in the bulk liquid is in sufficient quantity that bubble-cooling of the aqueous medium is greater than desirable, this behaviour will be sensed by temperature sensor 21 and, in response to a signal received therefrom by controller 22, valve 17 will be

actuated. In normal steam/air operation, valve 23 will be open (valves 24, 26 closed) and pressurized steam will be controllably admitted via valve 17 and conduit 16.

For air/oxygen operation, to be described in greater detail in relation to Fig. 2, valve 24 (for air) and valve 20a (for oxygen) would be the open valves.

With the entry of steam, the temperature of the system will be caused to rise from the combined effect of a) the inclusion of humidifying vapor within the air bubbles and, to a lesser extent, b) the heat content of the steam itself. Steam having entered the air bubbles reduces the amount of water that will evaporate inwardly from the surface of each bubble and thereby will reduce the expenditure of latent heat of evaporation. This reduction in cooling is accomplished without interfering with maintenance of the requisite operating level for oxygen dissolved in the aqueous medium. Automatic initiation and cessation of the introduction of steam and automatic setting of the rate of flow will maintain the temperature conditions preset in sensor 21.

Although electrical connections are indicated between controllers 19, 22 and valves 12, 17, respectively, these valves may be pneumatically actuated.

A second embodiment of the instant invention is set forth for air/oxygen operation in Fig. 2 wherein fermentation tank 30 is shown containing an aerobic biological reaction mass agitated and aerated by turbine 31, which draws air down draft tube 32 and mixes it with the aqueous reaction mass. Some oxygen from the air dissolves in the aqueous system to support the biological life forms growing therein, but (as in the previous embodiment) the bulk of the air remains gaseous in the form of small bubbles swept through the liquid mass by the vortex circulation induced by flat bladed turbine 31. Water evaporates into these bubbles up to the saturation point at the prevailing temperature.

When thermophilic digestion of cellulosic materials is being conducted in the fermentation tank (at operating temperatures of about 45-80°C), the vapor pressure of water is a substantial part of one atmosphere. Also, at the saturation point for oxygen in an aqueous system in equilibrium with air at 1 atmosphere and 55°C, the maximum dissolved oxygen concentration is about 5 ppm indicating the low equilibrium value of oxygen absorption.

Draft tube 32 is shown as a two-part structure consisting of a fixed upper wall 33 and a lower movable skirt 34. The arrangement of sensors and controllers shown in Fig. 2 is for operation with air and oxygen as the two gases employed. This combination of gases is, of course, illustrative.

When the temperature sensor 36 senses that the temperature of the liquid reaction mass has risen too much, the signal input to temperature controller 37 is such as to cause activation of servo motors 38 and 39 in a direction to lower skirt 34 supported thereby. As the bottom edge of skirt 34 moves closer to rotating turbine 31, the movement of air into the tank is gradually increased to a point at which sufficient cooling of the bulk liquid occurs and is reflected in the signal from sensor 36 to controller 37 to stop the servos 38, 39. When this increased cooling capability has reduced the temperature of the bulk liquid to a value below the set point for sensor 36, the signal from sensor 36 to temperature controller 37 will cause a reversal of servos 38, 39 bringing about an upward repositioning of skirt 34 as required. If desired, draft tube 32 can be a single piece structure, movable or fixed. When a single movable wall is employed, controlled movement thereof may be effected in the same manner as has been described with respect to skirt 34. If a single fixed wall structure is employed, the position of turbine 31 relative to the bottom edge of the draft tube may be varied by effecting upward or downward movement of the turbine 31 by appropriate activating means.

The open top of draft tube 32 connects aerodynamically and in sealing engagement with draft tunnel 41, that may be closed at both ends or open at one or both ends. If draft tunnel 41 is closed at both ends, vents (not shown) must be provided for the controllable admission of air thereto. Draft tunnel 41 is supported on the wall of tank 30 and may be extended therebeyond to the extent desired to ensure the intake of fresh air with minimal recycling of the hot humid air leaving tank 30. The structure of draft tunnel 41 must be capable of supporting draft tube 32, turbine 31 and the drive means 42 therefor.

Depending upon the necessity for sterile conditions, the portions of the top of tank 30 not covered by tunnel 41 may be closed or left open. Also, tunnel 41 may be wide enough to cover the full width of tank 30.

The initiation and cessation of the introduction of oxygen and the determination of the rate of flow thereof as the second gas to be introduced to the growth system is effected through the automatic control of valve 43 in conduit 44 by means of oxygen controller 46, which receives appropriate signals from oxygen sensor 47. Thus, when the air input has been curtailed in order to comply with temperature requirements, meeting the oxygen demands of the microorganism growth is assured by supplying oxygen as required through conduit 44.

The second gas is introduced into the

upper end of draft tube 32 and is thereby premixed with air in the growth system prior to entry into the growth medium and subsequent bubble formation, the energy for which is provided by agitator 31. In addition to the generation of water vapor within the bubbles so formed, there is, of course, the mutual interchange of oxygen (outward) and carbon dioxide (inward) with the surrounding liquid by gas permeation through the bubble wall.

In the event of premixing of the gases employed (as in Figs. 2 and as may be the case in the embodiment of Fig. 1 by terminating pipe 16 short of the outlet end of conduit 11) the temperature sensor/controller and the oxygen sensor/controller still exert their respective primary control functions. Thus, although in the embodiment in Fig. 2 the temperature control means (sensor 36 and controller 37) directly determines the introduction of air and the introduction of air in turn influences the oxygen concentration in the liquid medium, the oxygen control means (sensor 47 and controller 46) still has the primary responsibility of determining how rich in oxygen the premixed gaseous input must be.

Equipment required in the practice of this invention for the measurement of temperature and dissolved oxygen, the servomotor drives, automatically actuated valves and devices therefor, actuating linkages, etc., are standard commercial items. Although a single inlet pipe has been shown in each embodiment for the introduction of the second or oxygenating gas, a plurality of such inlet pipes may be employed, each connected to a pressurized supply of a different gas.

Figs. 3 and 4 graphically illustrate types of metabolic heat generation that may be encountered in practice in a thermophilic system and the relationship thereof with curves illustrating heat removal by the introduction of the oxygen-containing gas due to water evaporation into the gas bubbles generated therefrom in meeting the oxygen demands of the system.

Curve a of Fig. 3 is illustrative of the "metabolic heat minus heat losses" curve for a biological system having a low rate of heat generation. Curve b represents bubble heat removal encountered in meeting the oxygen demands of the biological system. The considerable space between curve a and curve b is indicative of the aggrevated overcooling condition that can be encountered in a thermophilic system. The practice of this invention is intended to enable curve b to be made coincident with curve a (BTU's removed = BTU's of heat loss) by the proper selection and control of a first or temperature controlling gas to be introduced in co-ordination with the air flow. The term "first gas" is intended to cover the situation in which a plurality of gases may be employed in sequence or combined in a single mixed input.

In operation, both heating and oxygenation of the system will generally be employed initially. Such initial heating may be accomplished by means of a conventional heating jacket (not shown) around the fermentation tank. Raising of the initial oxygen concentration (to 1-2 ppm dissolved oxygen) is preferably accomplished using the second gas (oxygen and steam) prior to encountering the cooling effect of the first gas input (air). Once the growth has been initiated (0 on curve a) and the metabolic heat generated in the system increases, the discussions relative to Figs. 3 and 4 apply illustrating the air/oxygen and the stream/air systems.

If the first and second gases introduced into a biological system that is producing heat at a low rate relative to the evaporative heat loss are air and oxygen, the air input (responsive to temperature sensing) will vary as a function of time from zero to a maximum value and will then reduce to some low value. During this same time the oxygen input (responsive to the oxygen sensor) will be such that the oxygen/air ratio will vary from a maximum to a minimum value (coinciding with maximum air input) and then will gradually increase thereafter.

In a biological system having a low rate of metabolic heat generation wherein air and stream are employed as the main gas inputs, steam (responsive to temperature sensing) is used in initial heating of the system and will be introduced all the way through the process at varying flow rates, because the air introduced (responsive to the oxygen sensing) would otherwise provide overcooling through the entire process as the air input meets the oxygen demand. This is a generalized description of the gas input interrelationships and a specific system would have to be considered for more accurate identification thereof.

As is shown in Fig. 4, in a system producing heat at a high rate, curve c would be representative of the "metabolic heat minus heat losses" as a function of time in a thermophilic system. Curve d indicates the heat removal as a function of time effected by the evaporation of water brought about by the introduction of air in accordance with the oxygen demands of the biological system. A condition in which heat generation exceeds heat removal exists between points A and B where curve c exceeds the maximum of curve d.

When such a system is operated with air and oxygen as the main gas inputs, once the system has been initially heated and oxygenated, the air input (responsive to temperature sensing) will increase from zero, only if

required for cooling, until point A is reached. Thereafter, air input is increased as required for cooling from A to X; air input is decreased as required for diminishing cooling requirements from X to B and air input continues to decrease from B in accordance with temperature requirements.

The supply of oxygen as the second gas introduced (responsive to oxygen sensing) expressed as the oxygen/air ratio begins at a maximum value, decreases to zero at point A, remains at this value to point B and then increases as is required.

When air and stream are used as the primary gas inputs, in a biological system in which heat is generated at a high rate, the introduction of air will be responsive to the oxygen sensing, while the steam input will be responsive to temperature sensing. After initial oxygenation of the system and simultaneous steam input to provide initial heating, the air input required from zero to A to satisfy the biological demand will require the introduction of steam at a decreasing rate to offset the excess cooling effect. Between point A and B the steam would be shut off and the air input would be increased by operation of a control (not shown) overriding the oxygen sensor to provide the requisite cooling effect even though oxygen is being supplied in excess of the biological demand. At point B the introduction of steam would be initiated at an increasing rate to offset the cooling effect of the air input.

This invention is applicable both to batch processing and continuous operation. In a continuous operation separate, but connected, fermentation tanks would be employed each of which would conduct a portion of the specific process. The continuous operation of stirred tank reactors is old in the chemical engineering art.

The functional relationships between tank diameter, agitator placement, agitator diameter, etc. are well known in the mixing art. The choice and location of the agitating means can be varied according to the needs of the growth system. For example, the agitating means may be designed for slow rotation or for high speed rotation.

Thus, particularly in a thermophilic biological growth process, significant economies can be realized by providing the capability for simultaneous delivery into the growth system of at least two gases, one responsive to an offet from the set point for temperature sensing in the growth medium and the other responsive to an offset from the set point for dissolved oxygen sensing in the growth medium. In each instance one of the two gases will be an oxygen-containing gas (usually air) while the other gas is typically steam or oxygen. The gases introduced into the growth system may be mixed at the point of entry thereof into the growth medium or premixing may be employed.

WHAT WE CLAIM IS:—

1. Apparatus for the conduct of controlled aerobic fermentations, said apparatus comprising in combination:

a) a growth tank containing a quantity of liquid medium therein for the growth of microorganisms;

b) an agitator located in said growth tank for agitating said medium;

c) a first gas inlet in flow communication with said growth tank for introducing a first gas thereinto;

d) a first gas detector connected to said first gas inlet for controlling the rate of gas admission therethrough;

e) a second gas inlet in flow communication with said growth tank for introducing a second gas thereto;

f) a second gas detector connected to said second gas inlet for controlling the rate of gas admission therethrough;

g) an oxygen sensor located in said growth tank for sensing the molecular oxygen content in said medium;

h) a temperature sensor located in said growth tank for sensing the temperature of said medium;

i) a first gas rate controller being connected to and responsive to signals from said temperature sensor and

j) a second gas rate controller being connected to and responsive to signals from said oxygen sensor.

2. An apparatus as claimed in claim 1 wherein at least one of said first gas inlet and second gas inlet is disposed with the discharge end thereof adjacent said agitator.

3. An apparatus as claimed in claim 1 or claim 2 wherein the agitator comprises a flat-bladed turbine and drive means therefor.

4. An apparatus as claimed in claim 3 wherein the first gas inlet comprises a conduit having the discharge end thereof close to the center of the turbine.

5. An apparatus as claimed in any one of claims 1 to 4 wherein the first gas inlet comprises a vertically extending draft tube.

6. An apparatus as claimed in claim 5 in which at least part of the draft tube is vertically adjustable.

7. An apparatus as claimed in any one of claims 1 to 6 wherein the second gas inlet comprises a conduit.

8. An apparatus as claimed in claim 7 wherein the conduit extends into the first gas inlet for at least part of the length of said conduit.

9. An apparatus as claimed in claim 8 wherein the discharge end of said conduit is within a vertically extending draft tube.

10. An apparatus as claimed in any one of claims 7 to 9 wherein the conduit is dis-

posed within a second conduit as the first gas inlet.

11. An apparatus as claimed in any one of claims 1 to 10 wherein each gas rate controller includes a controller device and an automatically adjustable valve operated thereby.

12. A process for the conduit of controlled aerobic fermentations comprising the steps of:

a) introducing aerobic microbial culture into an aqueous medium containing requisite nutrients and a source of carbon,

b) raising the oxygen content and temperature of said medium to levels at which the microbial culture can grow and multiply,

c) continuously sensing the temperature of said medium during the growth cycle,

d) continuously sensing the dissolved oxygen content of said medium during the growth cycle,

e) mixing a first gas with said medium continuously during at least part of the growth cycle,

f) mixing a second gas with said medium continuously during at least part of the growth cycle, said first and second gases being introduced simultaneously during only part of the growth cycle and being intimately mixed during the period of simultaneous introduction,

g) automatically controlling the rate of addition of said first gas to said medium in response to the temperature sensing,

h) automatically controlling the rate of addition of said second gas to said medium in response to the sensing of dissolved oxygen in said medium, at least said second gas containing at least 20 percent oxygen by volume and said first and second gases being selected from oxygen, air, steam, nitrogen and carbon dioxide.

13. A process as claimed in claim 12 wherein the first gas is air and the second gas is oxygen.

14. A process as claimed in claim 12 wherein the first gas is steam and the second gas is air.

15. A process as claimed in any one of claims 12 to 14 wherein thermophilic organisms are employed and the operating temperature is in the 45° to 80°C range.

16. A process as claimed in any one of claims 12 to 15 wherein the dissolved oxygen content is maintained in the 1-3 ppm range.

17. An apparatus for the conduct of controlled aerobic fermentations as claimed in claim 1 substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

18. A process for the conduct of controlled aerobic fermentations as claimed in claim 12 substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

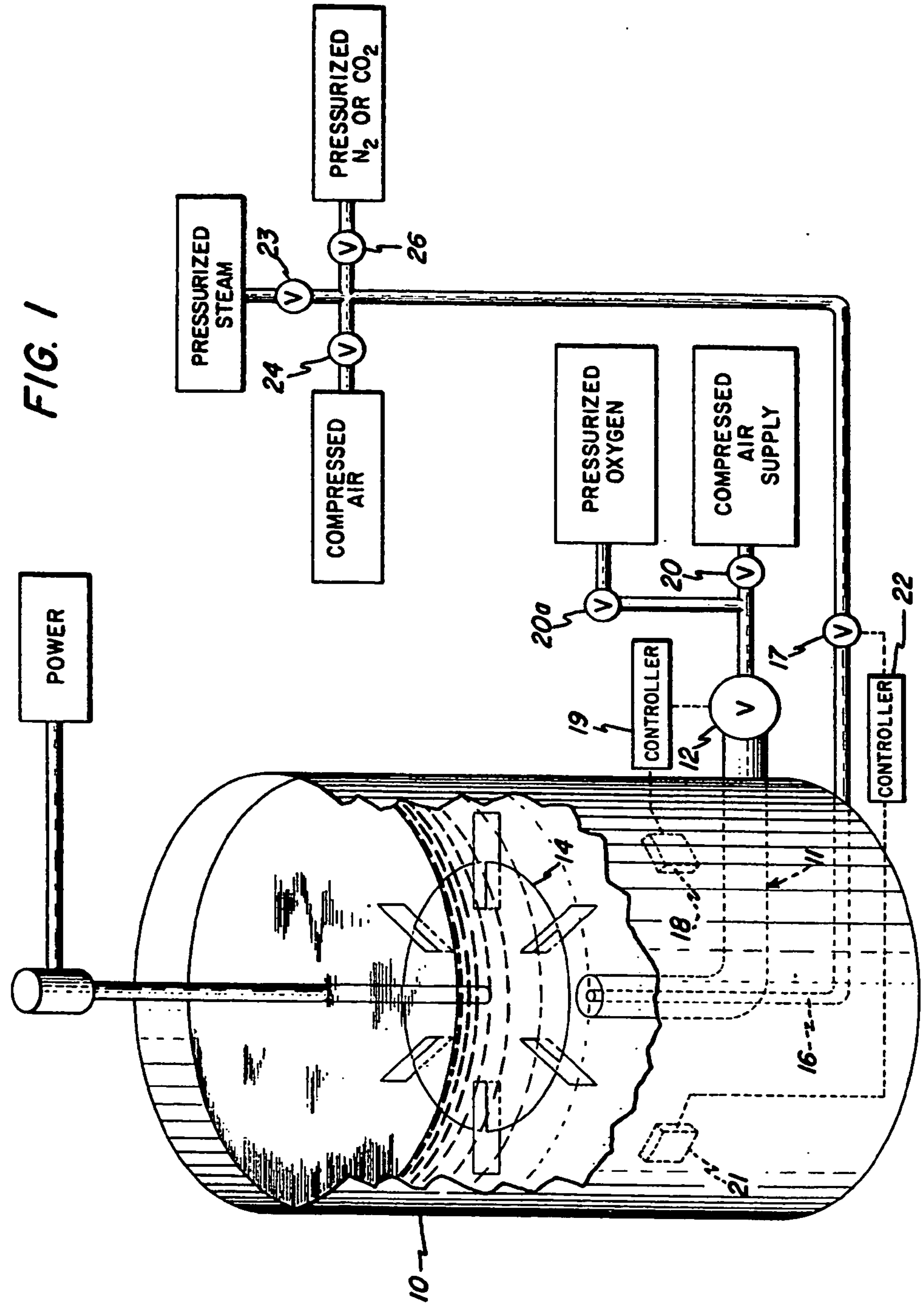
19. Aerobic fermentations when conducted in an apparatus as claimed in any one of claims 1 to 11 and 17.

20. Aerobic fermentations when produced by a process as claimed in any one of claims 12 to 16 and 18.

J. A. BLEACH
Agent for the Applicants.

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1976. Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

FIG. 1



BEST AVAILABLE COPY

FIG. 2

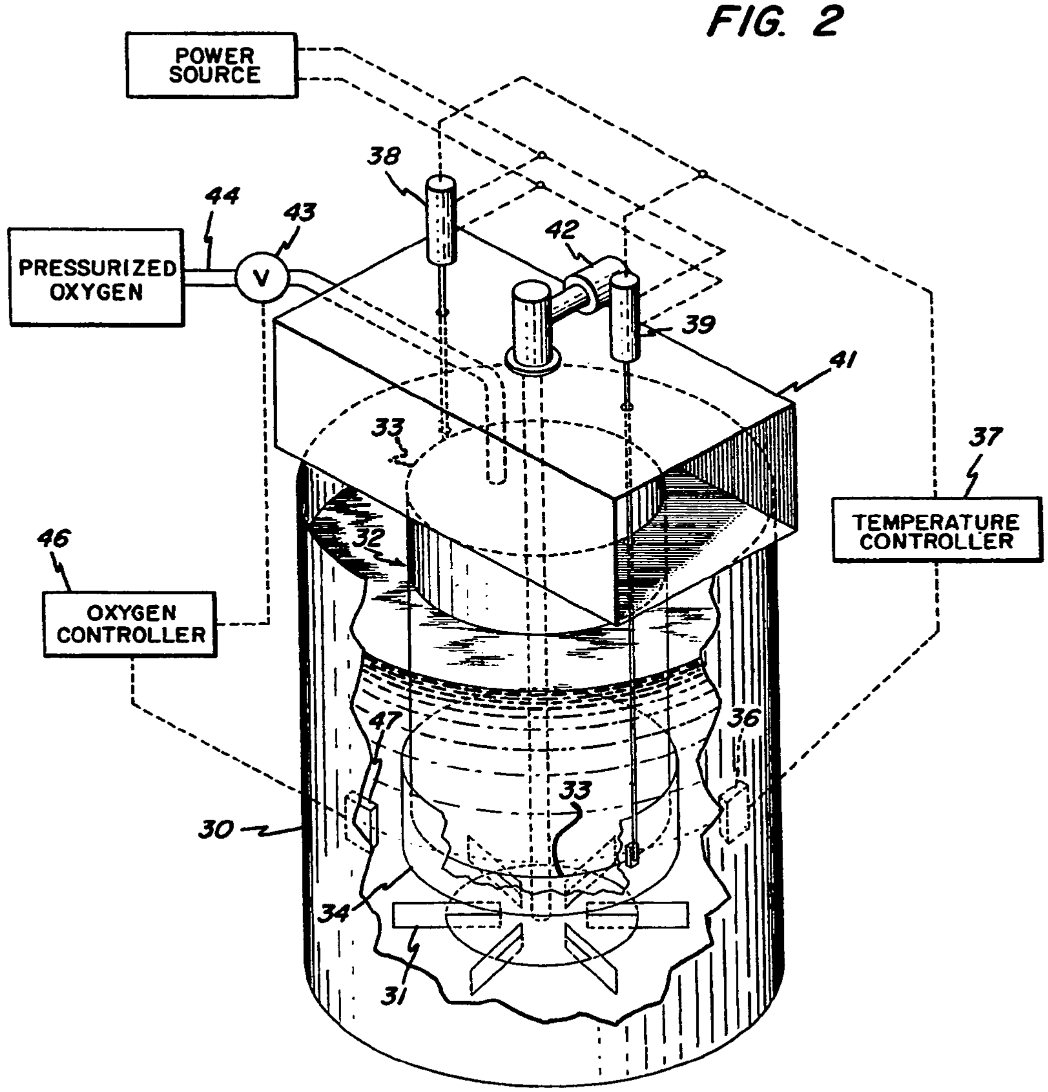

POWER SOURCE
38
44
43
42
PRESSURIZED OXYGEN
V
39
41
33
37
TEMPERATURE CONTROLLER
46
32
OXYGEN CONTROLLER
47
36
33
30
34
31

FIG. 3

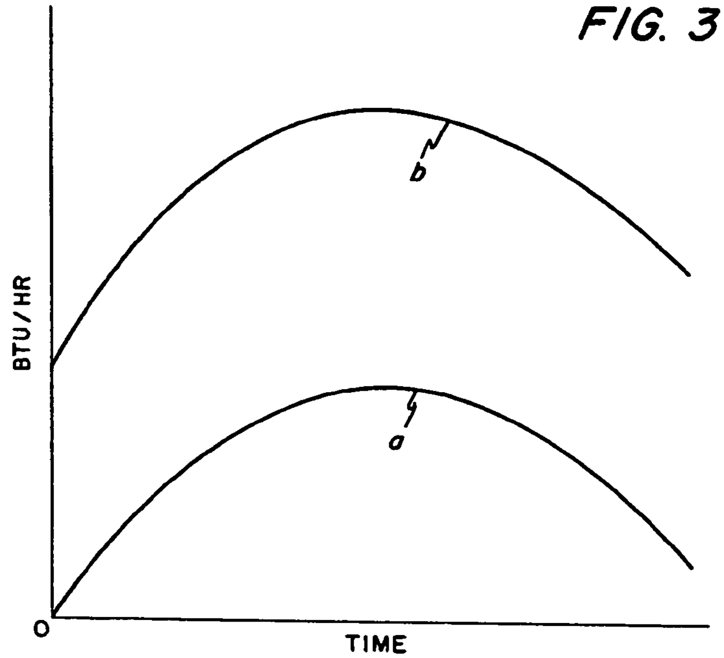


FIG. 4